BROOKS RESIDENTIAL FUEL CELL DEMONSTRATION PROGRAM

FINAL REPORT

SwRI® Project No. 05118

Prepared for

US Army Corps of Engineers
Construction Engineering Research Laboratory
P.O. Box 9005
Champaign, IL 61826-9005

May 28, 2004

SOUTHWEST RESEARCH INSTITUTE®
SAN ANTONIO HOUSTON WASHINGTON, DC

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May 28, 2004

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NONMENCLATURE

BAA	Broad Agency Announcement
BDA	Brooks Development Agency
CERL	Construction Engineering Research Laboratory
CHP	Combined Heat and Power
CPS	San Antonio City Public Service
DI	De-Ionizing (De-Ionized Water)
DOD	Department of Defense
GE	General Electric
kW	Kilowatt
kW-hr	Kilowatt Hour
LTS	Low Temperature Shift
PEM	Proton Exchange Membrane *or* Polymer Electrolyte Membrane
RO	Reverse Osmosis
SwRI	Southwest Research Institute
TCEQ	Texas Council on Environmental Quality
U.S.	United States (United States of America)

ACKNOWLEDGEMENTS

The author wishes to thank the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory for the opportunity to work on this program. Particularly, within CERL, Dr. Michael Binder for his program vision and support at the Brooks Residential Fuel Cell press event, Mr. Frank Holcomb for his program guidance and support of the kickoff meeting, Ms. Melissa White and Mr. Nicolas Josefick for standardizing data reporting and handling a great deal of data, Ms. Dana Finney for being so responsive and helpful with press releases, and Ms. Rita Brooks for all her contractual work to move the project along.

Thanks to San Antonio City Public Service for being a wonderful partner in the project. Valerie Harris, Joe Fulton, Jamie Axtel, Milton Lee and the CPS Board of Directors had the vision to move forward with the project and commit significant resources to help make the project a success. Marta Lopez was there at every turn, helping materially in construction, communications within CPS and day to day running. Harvey Scheffler took on design of a new facility and did a superlative job, as evidenced by our having no facilities problems throughout the demonstration. John Aelvoet and Bill Haby took on fuel cell training, tackled many new concepts and skills and spent many hours maintaining and troubleshooting fuel cells. Bob McCullough organized our press events and made them great successes.

Many thanks to Plug Power for the training and support on the fuel cells. Scott Wilshire stepped in promptly and offered the program a way forward when DCH Technology could not supply our fuel cells. Brian Davenport supported us in many ways including maintenance, troubleshooting and program guidance. Rob Lowen and Chris Ashley were great in the area of telephone support and parts shipment. Lisa Potter spent many hours helping with inverter interconnection standards. Ed Shively and Bill Kuiper put together and implemented a comprehensive and indispensable training program and were very patient with us.

Greg Philips from St. Philip's College put a great deal of personal effort and resources into laying the groundwork for the St. Philip's College fuel cell training program. Greg was a great supporter throughout the program.

Thanks to Mary-Rose de Valladares, formerly with DCH Technologies, who put great effort towards making the DCH Technology fuel cell work for the program.

Connected Energy deserves a great deal of credit for making the data acquisition and control system a very functional tool for running and maintaining the fuel cells and making virtually all the information available to the public in a real-time manner. Special thanks to Kevin Hann for bringing it all together and making it happen.

Personnel from Brooks Air Force Base and Brooks City-Base made the demonstration site available to the program and allowed us to monitor three base housing units. Thanks to Stephen Holt from the U.S. Air Force and Kirklan King from BDA for making all this possible. Thanks to the U.S. Air Force residents along Vinsant Circle who allowed us to record their energy usage during the program.

Thanks to Mark Walls from Southwest Research Institute who made many trips to Brooks

City-Base to maintain and troubleshoot the fuel cells. Mark's dedication to the program was the prime reason we were able to meet our 90% availability requirement.

EXECUTIVE SUMMARY

Southwest Research Institute® (SwRI®), under a contract from the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory (CERL), demonstrated three 5 kilowatt Proton Exchange Membrane (PEM) fuel cells at Brooks City-Base in San Antonio, Texas during the period February 6, 2003 through March 15, 2004.

The fuel cells, provided under the contract by Plug Power Inc., were fueled with natural gas and supplemented the power to three individual base housing units at Brooks City-Base. The units were grid connected and did not supply heat for any combined heat and power application. Other partners in the demonstration were City Public Service of San Antonio, St. Philips College, Connected Energy, the U.S. Air Force and Brooks City-Base.

We successfully installed, operated and monitored three PEM fuel cells, at Brooks City-Base, for a period of one year and one month. We provided feedback of information to CERL throughout the demonstration period. We achieved greater than 90% availability on all three fuel cells for a period of one year. During the demonstration period the fuel cells generated more power than was consumed by the base housing units.

We familiarized Brooks Air Force Base and Brooks City-Base personnel (and other military installations in the San Antonio and around the country) with fuel cell technology. We demonstrated the potential of environmentally friendly electric generation technologies to CPS customers.

We provided practical experience to CPS personnel in fuel cell siting, installation and maintenance. This firsthand knowledge will provide a basis for CPS to make decisions on future fuel cell projects and other alternative energy and distributed generation projects.

We provided the basis for a fuel cell education program for St. Philips College, Lamar Technical College and Texas State Technical College.

We provided a great deal of product feedback to Plug Power for their fuel cell operating in the San Antonio climate.

As a result of project activities, fuel cells running on natural gas or propane have been granted De Minimis status by the Texas Council on Environmental Quality. This means that future fuel cell projects will not require an air quality permit in Texas.

We were very successful in demonstrating a realistic view of fuel cell technology to the populace through lectures, site tours, articles, TV spots, and direct internet access. We constructed and maintained the first real-time fuel cell data site on the internet.

We successfully demonstrated limited remote control of fuel cells via the internet using the Connected Energy interface. This allowed password-protected control of fuel cell shutdown and power level (2.5, 4 or 5 kW) via any computer that has internet access. Control of energy production systems as distributed generation assets is an area that holds great promise for future research particularly in the area of homeland security and domestic energy security.

The Residential Fuel Cell Demonstration Program funded by CERL provided a wonderful venue

to advance fuel cell technology in a realistic and organized fashion. It has provided a common platform to evaluate different technologies in diverse climates and operating conditions.

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1.0 INTRODUCTION AND BACKGROUND

In fiscal years '93 and '94, the U.S. Congress provided funds for natural gas utilization equipment, part of which was specifically designated for procurement of natural gas fuel cells for power generation at military installations. The purchase, installation and ongoing monitoring of the fuel cells provided by these appropriations came to be known as the "DOD Fuel Cell Demonstration Program." This work was conducted under Work Unit CFE-B141, "Proton Exchange Membrane (PEM) Fuel Cell."

The mission of the Construction Engineering Research Laboratory (CERL), as stated in BAA CERL-BAA-FY01, is to, "increase the Army's ability to more efficiently construct, operate and maintain its installations and ensure environmental quality and safety at a reduced life-cycle cost." Fuel cells offer the promise of achieving many of these objectives, through their quiet, clean, efficient and potentially long-lived operation. CERL recognized this early on and, beginning in 1993, ran a successful demonstration of 30 phosphoric acid fuel cells powered with natural gas. CERL learned many lessons from this demonstration program and the fuel cell industry benefited from the experience.

Southwest Research Institute® (SwRI®) responded to broad agency announcement, CERL-BAA-FY01, entitled "PROTON EXCHANGE MEMBRANE (PEM) FUEL CELL DEMONSTRATION OF DOMESTICALLY PRODUCED RESIDENTIAL PEM FUEL CELLS IN MILITARY FACILITIES" in May 2001 with SwRI Pre-proposal No. EVR-3127, entitled "Demonstration of PEM Fuel Cells in Military Residential Facilities." Based on that pre-proposal, CERL requested that SwRI submit a formal proposal.

In July 2001, SwRI submitted Proposal No. 03-32209, "Demonstration of PEM Fuel Cells in Military Residential Facilities" to CERL. This proposal was a collaborative effort between San Antonio City Public Service (the gas and electricity utility in San Antonio), the U.S. Air Force at Brooks Air Force Base, St. Philips College and DCH Technology (a fuel cell manufacturer). SwRI was awarded a contract to install three PEM fuel cells at Brooks Air Force Base and demonstrate them for a period of one year. This report describes this work, performed under contract number DACA42-01-R-0024.

2.0 OBJECTIVES

The primary objective of this project was to supply a turnkey package for the installation, operation, maintenance, monitoring, data reporting, removal and site restoration of domestically produced residential fuel cells at a military facility. Pursuant to this objective we proposed to install, operate and monitor three PEM fuel cells, at Brooks Air Force Base in San Antonio, Texas, for a period of one year. Inherent in this objective was feedback of information to CERL to provide a basis for evaluation of fuel cell technology.

Secondary objectives included:

1. Familiarization of Brooks AFB personnel (and other military installations in the San Antonio area) with fuel cell technology,

2. Demonstrate the potential of environmentally friendly electric generation technologies to City Public Service customers,

3. Providing the basis for a fuel cell education program for St. Philips College,

4. Providing product feedback to the fuel cell manufacturer for their fuel cell operating in the San Antonio climate,

5. Demonstrate fuel cell technology to the populace through articles, TV spots, and internet access.

3.0 APPROACH

SwRI began coordination meetings between San Antonio City Public Service (CPS), the U.S. Air Force, St. Philips College and DCH Technology to agree on timing and project specifics. In June 2002 DCH Technologies filed a Form 8-K with the Securities and Exchange Commission which described the furloughing of all employees. DCH Technology subsequently disbanded its operations. SwRI contacted Plug Power Inc. (Plug Power) and began negotiations to provide three fuel cells for the Brooks Residential Fuel Cell Demonstration Program. SwRI requested and was granted permission from CERL to substitute Plug Power fuel cells for the DCH Technology units.

The units were Plug Power 5 kW model SU1R, powered with natural gas and operated in a grid parallel manner. We decided not to attempt combined heat and power (CHP) operation of the units due to a request from the Air Force to minimize interactions with the residents of three base housing units and to facilitate a central location for the three units. Additionally, initial estimates indicated that retrofitting the housing units with CHP would not yield significant efficiency improvements due to the sporadic usage of hot water in the housing units (some turnover of occupants was anticipated by the Air Force) and minimal space heating requirements in the San Antonio climate. A concept for a hot tub to be shared by the three housing units was rejected due to liability concerns.

Procurement of the SU1R fuel cells from Plug Power entitled the project team to six slots in a Plug Power training course. Two personnel from SwRI (Alan Montemayor & Mark Walls), two from CPS (John Aelvoet and Bill Haby) and one from St. Philips College (Greg Brady) attended the two week Plug Power "SU1 Installation & Service Training Program" at the Plug Power facility in Latham, NY in September 2002. Project funds paid for only the SwRI personnel. The course was a comprehensive and excellent summary of skills, knowledge and techniques necessary to install and run the fuel cells. Subsequent to this training, Marta Lopez from CPS attended one week of the training.

SwRI met with CPS personnel to discuss the design of the fuel cell site. At the time, there were no standards for fuel cell site construction, so we began with the concept of designing the site as a small utility substation or switchyard. CPS had designed and constructed many such facilities, so it was logical to use some of the same standards and practices to design the fuel cell facility. This decision proved to be a wise one, as many of the design features of the site proved beneficial throughout the demonstration.

CPS specified a 35 by 35 foot asphalt pad for the site with concrete pads for the fuel cells. The concrete pads were built according to the Plug Power installation manual. The all weather nature of the asphalt pad facilitated maintenance of the units under wet weather conditions. The asphalt pad also facilitated the use of hand trucks and moving dollies for moving many of the heavier maintenance items such as fuel cell stacks, catalysts, batteries and inverters. The pad also minimized influx of fire ants and weeds into the units.

CPS specified a fully fenced and gated facility. The fence provided security to the facility and yet allowed easy access to the facility for maintenance and tours. Because we had a secure facility, we were able to leave tools and battery chargers within the facility overnight and during lunch hours. There were limited buttons to push on the fuel cells, but we were assured that no children or curious individuals would interfere with the demonstration. This was a concern, since the base housing units in close proximity to the demonstration were known to have children in them. The fence also provided a

good place to mount our facility sign and allowed us to post "Danger High Voltage" signs as required by CPS policies.

In accordance with their standard substation practices, CPS specified and installed a grounding grid beneath the asphalt pad. The grid consisted of heavy gauge copper wire buried beneath grade in a grid layout and grounded to the fence posts and conduits of the facility. The intent of the grounding grid was twofold: to assure that no voltage from the facility could electrify the fence or conduits and create a personnel hazard and to insure that lightning would have a preferred path to ground that did not pass through our test equipment. The grid apparently performed well, as we experienced no problems with hazardous voltages or lightning damage throughout the demonstration.

CPS also provided elevated lights for the site and service electricity on the pad. The Air Force had requested that we not make extensive use of the lights to preserve the darkness and privacy of the nearby housing units. We did not use the lights throughout the demonstration. Figure 1, Fuel Cell Installation, depicts the three fuel cells of the installation.

Figure 1. Fuel Cell Installation

The U.S. Air Force allowed us to instrument three base housing units located at 107, 109 and 111 Vinsant Circle for electrical energy consumption. CPS chose General Electric (GE) kV-2 electric

meters for this task. The Air Force base housing office asked that we minimize contact with the personnel in the base housing units and that we minimize any interruptions to their electric power. SwRI contacted the personnel living in the units at the initiation of the project to inform them of their passive role in the project. Only one of the residents responded and expressed interest in the project. We sent him information on the project. Figure 2. Base Housing Unit, depicts one of the base housing units we monitored throughout the test.

Figure 2. Base Housing Unit

During the course of the project, Brooks Air Force Base became Brooks City-Base. Our point of contact switched from the Air Force Facilities Engineering office to Brooks Development Agency (BDA). SwRI negotiated lease of the land for the facility and use of a small maintenance building, building 514 from BDA at no cost to the project. BDA provided keys to building 514 and allowed us to use the building as a site for our reverse osmosis water filtration equipment and as a place to store spare parts. Use of building 514 proved very advantageous for the project as it provided a dry, warm and secure storage area for all the project supplies. It was necessary to protect the water filtration units from freezing and building 514 proved to be ideal for this purpose. The water filtration units from Plug Power consisted of a rust and scale filter, followed by a reverse osmosis (RO) unit followed by a polishing filter. Plug Power refers to the filtration system as the de-ionized (DI) water system

Obtaining metered water and drainage for the DI water systems proved to be somewhat difficult. Water was available in building 514 but San Antonio building codes required a metered tap and backflow prevention in order to utilize the water for an "industrial" application. San Antonio Water System (SAWS) was very helpful in providing backflow prevention and metering for the project at no charge. We examined the possibility of using recycled water from SAWS to supply the system. The recycled water was available in close proximity, but the solids content of the water made it unattractive as feed for our RO water purification system.

The existing drain in building 514 drained to a shallow pit with crushed limestone in it. During times of high rainfall, the drain would back up and put as much as 1 inch of water onto the floor of building 514. The existing drains were deemed inadequate for our project wastewater so CPS engineered a small lift pump system to carry our wastewater (estimated at up to 300 gallons per day) to a rainwater drain some 120 feet from building 514. We also looked at injecting the reject water from the RO system back into the recycled water system, but would have had to qualify the water to do so. The lift pump worked well throughout the project.

San Antonio water is hard, that is it contains a great deal of calcium carbonate. The water is saturated with calcium carbonate because it is obtained from a limestone aquifer. Many other communities have hard water as well. Fuel cells require very pure water. Calcium carbonate is undesirable because it precipitates out on the internal surfaces of the fuel cell and will cause fouling and scaling. For that reason the calcium in the water must be removed.

For very hard water like San Antonio's, Plug Power's fuel cell specification requires a water softener to partially remove the calcium carbonate before the water is introduced into Plug Power's water polishing unit. We initially considered installing a water softener upstream of the DI water system. Due to the added expense of purchasing and operating an ion exchange water softener, we elected not to use the water softener because it did not make sense for a one year demonstration. For a permanent installation in the San Antonio area, a water softener WOULD be required. Calcium carbonate deposits on the RO filter as the water passes through it. Because of the high calcium carbonate concentrations the filters clog much faster.

Since building 514 was located approximately 100 feet from the fuel cells, we chose to increase the diameter of the water tubing that connected the DI filters to the fuel cells from ¼ inch to 3/8 inch. The polypropylene tubes were run entirely underground to prevent freezing (not much of a problem in South Texas). This obviated the need to hot water trace the lines. The longer and larger tube size did take longer to fill than a smaller/shorter tube.

CPS obtained all the City of San Antonio required permits for construction and operation of the facility. The fire department required that we have a paved road to the facility, so CPS specified an asphalt road leading from Bedwell Road to our facility, a distance of approximately 300 feet. The road proved to be very beneficial when we were forced to do maintenance in wet weather conditions, allowing us to back our maintenance trucks up to facility without fear of becoming mired in mud.

CPS also applied for the air quality permit from the Texas Council on Environmental Quality (TCEQ), the air quality permitting agency for Texas. TCEQ personnel informed the project team of the existence of a De Minimis list for processes deemed to be clean enough to not require an air quality permit. Plug Power applied for and was granted De Minimis status for all fuel cells less than 1 megawatt running on natural gas or propane in the State of Texas. This effort effectively paves the way for future fuel cell projects in Texas by eliminating the application for an air quality permit.

SwRI chose Connected Energy to design and install a web based data acquisition and control system to monitor and control the fuel cells, gas meters and electric meters. Connected Energy had prior experience in monitoring Plug Power fuel cells and was working with Plug Power on the interface with their fuel cells. The fuel cells required a ModBus communication protocol that Connected Energy was familiar with. Connected Energy also provided a database to store the information from the demonstration and a web-based interface to make the information available to CERL, project partners

and the public. Connected Energy's software allowed different levels of access to the site so that SwRI could have one level of information access and control and the public another. In cooperation with Plug Power, SwRI negotiated which fuel cell parameters would be available to which groups. This was necessary to protect Plug Power's proprietary information. Ultimately, SwRI created and maintained a web site to act as a front end for the Connected Energy system. The web site is:

www.swri.org/fuelcell

It provided what we think was the first real-time access for the public to operational fuel cells. Figure 3, Site Summary Screen, depicts one screen of the data available on the Connected Energy web site.

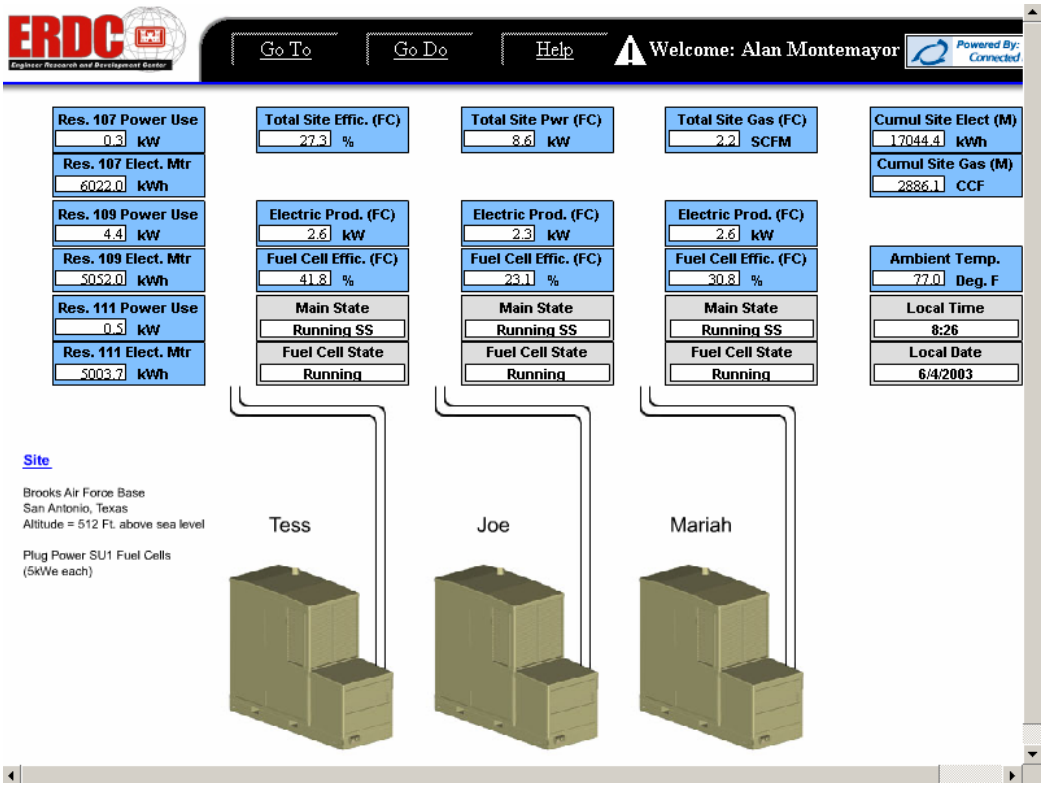

Figure 3. Site Summary Screen

We opted to monitor the gas meters and electric meters that measured gas inlet and electrical output from each fuel cell to act as the measures of efficiency on the project. This same information was available on the communication bus from the Plug Power system, but we wanted to account for all energy consumed and produced by the fuel cells. The Connected Energy system monitored three natural gas meters, three electric meters, three fuel cells and three electric meters on the base housing units. This provided a comprehensive data stream that was valuable for troubleshooting as well as data analysis. CPS calibrated all gas and electric meters at the beginning of the project and checked them at the completion of the project to assure accuracy of the data. The gas meters were instrumented with simple magnetic pulse generators that generated one pulse for each cubic foot of gas that passed through them. It was a simple task for the Connected Energy equipment to count the pulses and accumulate fuel usage information.

We experienced a great deal of difficulty in getting the GE kV-2 electric meters to communicate over a common ModBus interface. Although the units were designed to communicate in this manner, GE was not aware of the problem and was unwilling or unable to assist us in solving the problem. This was unfortunate since CPS is a large customer for GE and the experience was frustrating, to say the least. Ultimately, we installed optical isolation units on each meter to allow us to communicate with them.

Throughout the course of the demonstration, we experienced sporadic communication dropouts on the kV-2 meters. The interruptions were not frequent (we experienced approximately 10 dropouts during the one year course of the project) but were disruptive since we were not able to record instantaneous data during the data dropouts. The only way to get the meters functional again was to electrically bridge across input and outlet lugs (to prevent fuel cell outages), remove the meters, wait one minute, and then re-install the meters. It was necessary to call CPS personnel to do this operation since it was necessary to perform the operation "hot". The meters continued to accurately accumulate kW hours during the periods of communication difficulties, so we did not lose any cumulative data. Based on our experiences with the GE kV-2 meters, it would be wise to use a different communication protocol or a different meter for future fuel cell projects.

SwRI received the fuel cells from Plug Power in advance of when the site was ready for installation. We stored the fuel cells in covered storage at SwRI until the site was ready. CPS moved the fuel cells from SwRI on a flatbed truck and used a crane at the site to load them onto the concrete pads. We brought all connections to the fuel cell underground including natural gas, 240 volts alternating current, control lines connecting fuel cell to disconnect panel, a 48 volt direct current water solenoid connection and ModBus monitoring/control line. In order to prevent any natural gas from entering electrical conduits, CPS sealed electrical conduits with a polymeric compound that hardened and provided a hermetic seal.

Installation of the fuel cells and instrumentation was complete in early February 2003. On February 6, 2003 we scheduled CPS to be at the site to witness fuel cell startup and a test of the control system anti-islanding feature. We christened the fuel cells Tess, Joe and Mariah to represent Plug Power serial numbers SU01R000000009, SU01R000000004 and SU01R000000013 respectively. The names are taken from a musical named "Paint Your Wagon" which contains a song entitled, "They Call the Wind Mariah". The names represent the three elementals rain, fire and wind, respectively, which in turn represent the DI water, heat and air (oxygen) necessary to operate the fuel cells. Naming the fuel cells made it easier to refer to them and gave them some personality.

All three units started and operated well on February 6, 2003. The anti-islanding test consisted of pulling the electric connection to the grid and monitoring whether or not each fuel cell disconnected as designed. The test worked well, with each fuel cell disconnecting itself promptly after loss of grid. CPS was satisfied with the test and approved entering the running phase of the project. CPS electronically zeroed all the electric meters (Tess, Joe, Mariah, 107 Vinsant Circle, 109 Vinsant Circle and 111 Vinsant Circle). We recorded initial readings of the gas meters and adjusted the data acquisition system to read the meters appropriately.

We initiated a grand opening event on February 19, 2003 and had over 200 people in attendance. Dr. Michael Binder from CERL spoke at the grand opening. We issued a CERL approved press release concerning the grand opening.

4.0 DISCUSSION OF RESULTS

We experienced communication difficulties with the fuel cells beginning on February 6, 2003. After the cable connection was installed and tested, the fuel cells would not communicate with the data acquisition system over the ModBus communication line. This took numerous iterations to resolve the difficulties, ultimately requiring that we load new control software on all three units. Communication issues with all three units were resolved February 10 –14, 2003. During the course of resolving the communication and software difficulties, we brought the units up and down numerous times. This lead to the failure of the low temperature shift (LTS) catalyst on all three units. Plug Power utilized an experimental LTS catalyst for these units, one that was intended to improve efficiency. Unfortunately, the on-off cycling of the units deactivated the catalysts, requiring downtime to replace the LTS catalyst units. With the help of a Plug Power technician, we replaced the LTS catalysts on all three units on March 4, 2003. Tess began running with the new LTS catalyst on March 4, 2003, Mariah on March 6, 2003 and Joe on March 14, 2003.

Running data for the entire program is summarized in Appendix A, Summary of Monthly Data. These tables include all data from February 6, 2003 through March 15, 2004 in the case of Tess and Joe and the period February 6, 2003 through February 22, 2004 for Mariah. Availability's summarized in the tables are availability's over the entire running period, including extended downtime at the beginning of the demonstration caused by the aforementioned reformer difficulties.

In addition to energy produced and natural gas consumed, Appendix A contains an analysis of the cost to purchase the natural gas for the fuel cells and the value electricity produced from the fuel cells, valued as if it were purchased from the grid. All costs are based on residential rates from CPS.

The cost of grid power includes the following components: capital cost of the power plant, capital cost of the electric transmission and distribution lines, interest on debt, fuel, operating and maintenance expenses (water, consumed chemicals, labor), metering and billing. Of the 6-9 cents per kWh residential rate in San Antonio, fuel and generation plant operating costs average 2 cents per kWh. The fuel cell gas cost only represents one component of the delivered energy price. Cost components not listed include capital costs and interest, installation costs, cost of replacement parts and labor, cost of consumables such as water and other chemicals. Maintenance performed on the units is summarized in Appendix B, Maintenance Log.

In early August, 2004, San Antonio experienced ambient temperatures of approximately 109 degrees Fahrenheit. The fuel cells operated well during this period with no noticeable decline in power. We were running at a power setting of 4 kW during this timeframe, less than the peak power setting of 5 kW. There were fuel cell maintenance issues during this period, but none of them were related to high temperature.

One of the contractual requirements was that we attain 90% availability for a period of one year. We easily made that requirement on Tess and Mariah but Joe experienced numerous failures that made it necessary to run an additional month and one week to attain the 90% availability. We requested, and CERL granted, a no-cost time extension to accomplish this. Tess achieved **96.2%** availability for the one year period of March 5, 2003 through March 4, 2004. Joe achieved **91.6%** availability for the one year period of March 15, 2003 through March 14, 2004. Mariah achieved **93.9%** availability for the one year period February 22, 2003 at 2200 hours through February 22, 2004 at 2200 hours.

On average, natural gas costs to run the fuel cells cost more than simply buying electricity from CPS equivalent to the amount of electricity that was produced from the fuel cells. Based on residential rates for natural gas and electricity, summarized in Appendix A, it cost $96.45 per month more than the electricity produced to run Tess, $161.19 to run Joe and $123.21 to run Mariah. This cost was exacerbated by high natural gas costs and the fact that we did not attempt any combined heat and power applications.

Efficiencies on Joe were lower than the other two units and Joe required more stack changes than the other units. Although we had Plug Power technicians out several times, we were unable to adequately diagnose why Joe performed poorer than the other machines. Even after stack changes, it was never up to the efficiencies of the other units. Plug Power acknowledges this in their post test report included as Appendix C, Plug Power End of Demonstration Report. There appears to be a downward trend in the efficiencies of each unit with time, even taking into consideration stack replacements. That is to say that peak efficiencies after stack replacements appear to degrade slowly over the year of the demonstration. Plug Power indicates that system efficiency is driven primarily by reformer efficiency (it's ability to convert natural gas into hydrogen) and stack efficiency (it's ability to convert hydrogen into electricity).

Mariah shut down on February 22, 2004 for an undiagnosed failure. We chose not to restart it since it had already exceeded one year of run time and had made greater than 90% availability. We restarted Mariah only briefly to take a reformate sample on March 15, 2004. The low hydrogen content of Mariah's end of demonstration reformate sample may have been caused by Mariah not being fully warmed up or the reformer not functioning correctly because of the previous problem. Reformate analysis was performed according to ASTM D1946-90, Standard Method for Analysis of Reformed Gas by Gas Chromatography.

Beginning in October 2003, CERL requested that we submit monthly reports in a specific format. These reports (October 2003 through March 2004) are concatenated and included as Appendix D, Monthly Data Reports.

Throughout the program, the three fuel cells consumed 24,597 cubic feet of water. This is approximately 8,000 cubic feet per fuel cell for the one year and one month demonstration or approximately 168 gallons per day per fuel cell. This number is somewhat inflated, in that a small water leak (downstream from the meter) went unrepaired for a period of three months during the demonstration. It was originally thought that the water leak was upstream of the meter, but upon effecting repairs, we noticed that it was downstream of the meter and was therefore contributing to totalized water consumption. The magnitude of the leak is unknown.

Mariah completed operations on February 22, 2004. Tess and Joe ran till March 15, 2004. The fuel cells were removed on April 13, 2004. Plug power donated Tess to Texas State Technical College in Waco, TX, Joe to St. Philips College in San Antonio, TX and Mariah to Lamar University in Beaumont, TX. SwRI helped load Tess and Mariah onto university owned trailers and delivered Joe to St. Philips College using our own truck.

Throughout the program we had numerous opportunities to give tours of the facility, speak of the program to groups, and issue press releases and magazine articles. In all cases, where advance

notice was available and written copy was distributed, CERL was given editorial review before information on the project was made public. Public relations activities included:

- December 11, 2003 - Val Harris (CPS) delivered Fuel Cell/CHP Briefing to CPS Citizen Advisory Committee
- October 31, 2002 – Albany, NY – Alan Montemayor presents briefing to CRN-EPRI Residential Fuel Cell Demonstration Users Group Meeting
- Jan 8, 2003 - Milton Lee delivered a briefing on our Fuel Cell program at the Large Public Power Companies CEO Roundtable
- February 18, 2003 - Official Public Ceremonial Event for fuel cells. According to DOD's CERL, the turn out was twice the size of any similar event they've held in the past. The event was widely covered by the San Antonio news Media.
- February 26, 2003 - The fuel cell program was featured to the SwRI board. Alan Montemayor delivered a 10 minute presentation.
- March 2003 - The fuel cells were featured on television on the CPS Home & Lifestyle Show.
- March 24, 2003 – Houston, TX - Alan Montemayor presents Brooks project at 7th Annual Distributed Generation & On-Site Power Conference
- April/May, 2003 - Fuel Cells/Distributed Generation featured in CPS's internal corporate newsletter, the "Broadcaster."
- March 11, 2003 - Trinity engineering faculty Dr. Fred Loxsom and students toured CLC and Residential Fuel sites.
- June 2, 2003 - San Antonio - The fuel cells were featured to an audience of 60-80 conference attendees at a DOE-sponsored event entitled "Distributed Resources Roadshow" Tours of the fuel cell facilities were conducted and the event was featured on San Antonio News channel 9.
- June 11, 2003 - San Antonio - Val Harris & Alan Montemayor delivered a 25 minute project review presentation at DOD's CENET Annual meeting. The meeting was attended by CERL's Research Planning Advisory Committee, DOD Regional IMA (Energy Coordinators) and other military base energy managers. Tours of the fuel cell facilities were provided as well. Presentation was well received and resulted in invitation to Association of Energy Engineers Conference in December, 2003 (see below). Upon completion of the program, the DOD would like to feature the fuel cells in one of their military publications.
- September 18, 2003 - Skip Mills, Texas Engineering Extension Station, provided a tour and discussion of the fuel cells for Ira Flatow, National Public Radio's Science Friday Show moderator. The fuel cells were specifically mentioned on the National show the following day. His show was broadcast from Brooks City-Base.
- September 24, 2003 - San Antonio – Alan Montemayor delivered a presentation at the Biennial Meeting of the Association of State Energy Research and Technology Transfer Institutions. Fuel cell tour provided.
- September 28, 2003 – Fredericksburg, TX – Alan Montemayor presents Brooks Project at the Renewable Energy Roundup & Green Living Fair
- November 20, 2003 - San Antonio - MPE Renewable and Sustainable Buildings Conference. Fuel Cells were featured at a presentation of CHP Systems. Fuel Cell tour provided.

- Dec 12, 2003 - Alan Montemayor presents the Brooks project at the Association of Energy Engineers Conference.
- January/February 2004 – Brooks Residential Fuel Cell Project has a cover story in Defense Communities magazine, entitled, "Fuel Cells: Laying the Groundwork for Alternative Power in Communities).
- March 11, 2004 – San Antonio – Alan Montemayor presents "Fuel Cells 101" Presented at the Fuel Cells Literacy Conference hosted by St. Philips College
- The data from the fuel cell program are available on the Internet at a DOD CERL website. Links to the website are also provided by SwRI, CPS, as well as others. This was the first "real time" data on fuel cells on the internet.
- The Electric Power Research Institute has requested, and obtained permission to use the data on the public website for research purposes and will be including the results of the fuel cell program in their website materials and technical reports.
- The American Gas Foundation has submitted a request to CPS to use the data from the fuel cell site as a case study to prepare a congressional position paper on Distributed Resources. The work is in progress.
- Dub Taylor, State Energy and Conservation Office, recognized the significant contribution CPS has made with the Fuel Cells at his CPS Innovator Award comments.

Maintenance on the units was 50 hours for Tess, 100 hours for Joe and 65 hours for Mariah. These hours represent actual on-site work hours but do not include hours waiting for units to come up to power nor travel time to and from the units. None of the servicing was particularly difficult, but the Plug Power training course was invaluable in preparing us for the maintenance. It was helpful to have the Plug Power technician on-site for the catalyst replacement, since this was not an activity that was covered in training. Our units were located 15 miles from SwRI, requiring a round trip of 30 miles and approximately 40 minutes of travel time per maintenance incident. We had five personnel available for maintenance, with four people providing the preponderance of maintenance. This was a good ratio of technicians to fuel cells (5:3) because individual personnel were sometimes unavailable when a fuel cell went down.

The Connected Energy data acquisition system was key to alerting us promptly when maintenance was required. The Connected Energy system alerted the maintenance team via email when a unit went down. We had some fine tuning to do in the alert system, since occasionally the units would dip in power output without going off line. This fooled the system into thinking that the units had gone off-line when in fact they simply had a power dip. Connected Energy implemented both a low power alarm notification and a unit shutdown notification. We would typically check for malfunctions early in the morning and send service personnel out that morning. The Connected Energy system provided limited diagnostic data that always required on-site computer interface to diagnose the problem further to implement a fix. When we needed parts, we would alert Plug Power technical support and they would overnight ship a part to us. This one day parts lag (minimum) lengthened the downtime for any individual incident. The fuel cells seemed to have a perverse way of going down on Friday, Saturday or Sunday, the days when our response time was necessarily longer or shipment of parts was longer. We did not have spare parts inventoried on-site and ready for installation.

We used the Connected Energy system to help us predict when the fuel cells would need servicing by looking at the efficiency degradations. In daily checks of each fuel cell, we found that the

key numbers to check to assess unit health were efficiency versus time (looking for any sudden dips or long term degradation) and power output versus time (looking for any dips or downward trends). We also looked at DI water tank levels to see if we could catch a change in the filling characteristics versus time and change/adjust filters to avoid downtime. There is a great deal of useful work that could be done to identify incipient failures in advance of failure and alert service personnel in time to implement an efficient fix. This could minimize unit downtime.

We successfully demonstrated limited remote control of fuel cells via the internet using the Connected Energy interface. This allowed password-protected control of fuel cell shutdown and power level (2.5, 4 or 5 kW) via any computer that has internet access.

Having independent gas and electric meters proved to be a good choice for the project. There were some instances where the GE kV2 meters quit reading and it was very helpful to have the fuel cell internal power data to monitor the state of the fuel cells. Also, the external gas meter tended to show more gas flow than the internal meter, perhaps accounting (correctly) for startup gas used by the fuel cells.

Mariah completed operations on February 22, 2004. Tess and Joe ran till March 15, 2004. In total, Tess generated 24,564 kW-hrs, Joe generated 22,215 kW-hrs and Mariah generated 23,387 kW-hrs of electricity throughout the demonstration. Over the running period of the fuel cells, the base housing units consumed 23,370 kW-hrs at 107 Vinsant Circle, 16,531 kW-hrs at 109 Vinsant Circle and 12,406 kW-hrs for 111 Vincant Circle. Average power output for the fuel cells was 2.82 kW for Tess, 2.82 for Joe and 2.89 for Mariah. We chose to run the fuel cells at 2.5 kW setting for all months except August, September and October, 2004 when we ran the fuel cells at the 4 kW setting. We felt that maintenance increased at the 4 kW setting. Because we were trying to meet the 90% availability number, we reset the units to the 2.5 kW setting beginning in November, 2004 and left them there for the remainder of the demonstration. Even at this relatively moderate power output for each fuel cell, they generated more on average than each residence consumed. The base housing units, however, may not demonstrate typical usage patterns, since residents came and went during the course of the demonstration, causing times of low energy usage between tenants. Table 1, Brooks Housing Units, describes the housing units monitored throughout the test.

Table 1. Brooks Housing Units

Building Number	Address	Living Area	Electricity Consumed
495	107 Vinsant Circle	1524 Square Feet	23,370 kW-hrs
494	109 Vinsant Circle	1524 Square Feet	16,531 kW-hrs
493	111 Vinsant Circle	1467 Square Feet	12,406 kW-hrs

Average electrical efficiencies were 24.09% for Tess, 17.73% for Joe and 21.96% for Mariah. The reason for the low efficiencies on Joe were never fully understood although we had a Plug Power technician here to look at the units and sent numerous data files to Plug Power. The efficiency numbers represent external gas and electric meter numbers, truly measuring overall efficiency including startup and shutdown gas usage. Gas and electric meters were calibrated before the test by CPS and calibration

was checked at the completion of test at the CPS laboratory. All meters were certified as accurate within the required CPS standards.

Brooks Development Agency decided not to renew our lease on the property due to a commercial development that is slated in that area. We removed the entire above ground facility, leaving conduit, asphalt pad, concrete fuel cell pads, and fence footings in the ground. The fencing hardware was donated to the Texas Cave Management Association, a non-profit organization that manages and conserves cave resources. All switches, lights, wires and materials from the fuel cell site were either re-used or recycled. Above ground demolition was complete May 10, 2004. Brooks Development Agency plans to remove four feet of earth in the area of our demonstration and will likely demolish the remaining subterranean objects in the process.

5.0 CONCLUSIONS

We had a very successful demonstration of fuel cell technology. We supplied a turnkey package for the installation, operation, maintenance, monitoring, data reporting, removal and site restoration of three domestically produced residential fuel cells at a military facility. We successfully installed, operated and monitored three PEM fuel cells, at Brooks City-Base, for a period of one year and one month. We provided feedback of information to CERL throughout the demonstration period. We achieved greater than 90% availability on all three fuel cells for a period of one year.

We accomplished all of our secondary objectives as well.

We familiarized Brooks personnel (and other military installations in the San Antonio area and around the country) with fuel cell technology. We demonstrated the potential of environmentally friendly electric generation technologies to CPS customers.

We provided practical experience to CPS personnel in fuel cell siting, installation and maintenance. This firsthand knowledge will provide a basis for CPS to make decisions on future fuel cell projects and other alternative energy and distributed generation projects.

We provided the basis for a fuel cell education program for St. Philips College, Lamar Technical College and Texas State Technical College.

We provided a great deal of product feedback to Plug Power for their fuel cell operating in the San Antonio climate.

We were very successful in demonstrating a realistic view of fuel cell technology to the populace through lectures, site tours, articles, TV spots, and direct internet access. We constructed and maintained the first real-time fuel cell data site on the internet.

We successfully demonstrated limited remote control of fuel cells via the internet using the Connected Energy interface. This allowed password-protected control of fuel cell shutdown and power level (2.5, 4 or 5 kW) via any computer that has internet access. Control of energy production systems as distributed generation assets is an area that holds great promise for future research particularly in the area of homeland security and domestic energy security.

As a result of project activities, fuel cells running on natural gas or propane have been granted De Minimis status by the Texas Council on Environmental Quality. This means that future fuel cell projects will not require an air quality permit in Texas.

Fuel cell, microturbine, Stirling engines and other renewable energy technologies (solar photovoltaic, solar heating, wind power) hold great promise for increasing the energy efficiency of individual structures and enabling construction in areas not serviced by existing utilities.

The Residential Fuel Cell Demonstration Program funded by CERL has provided a wonderful venue to advance fuel cell technology in a rational and organized fashion. It has provided a common platform to evaluate different technologies in diverse climates and operating conditions.

6.0 RECOMMENDATIONS

We recommend that CERL continue the Residential Fuel Cell Demonstration Program and consider other types of fuel cells as well. We recommend emphasis on CHP, particularly where design of the fuel cell system into a new structure could significantly increase overall system efficiency by careful matching of fuel cell heat emission characteristics and building needs.

We recommend adding an emissions characterization program for the fuel cells that quantifies the benefit of the fuel cells within areas concerned with non-attainment of EPA clean air standards.

We recommend expanding the program to include renewable technologies. Expanding the program to include renewable technologies such as photovoltaic and wind would benefit many segments of society and expand knowledge of other distributed generation technologies.

We recommend investigation of distributed generation technologies that stress remote control of the assets to achieve peak shaving, power factor correction, homeland security and other goals associated with distributed generation. We recommend continued standardization within COE and DOD of common building control and monitoring protocols.

Appendix A
Summary of Monthly Data

Appendix B
Maintenance Log

Appendix C
Plug Power End of Demonstration Report

Appendix D
Monthly Data Reports